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Solar Insolation at Chennai during the 23rd Solar cycle

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Abstract:

The Solar irradiance is treated as a constant (solar constant) for many practical purposes. But, actually it varies by a small amount due to various causes. The objective of this paper is to emphasize the variations produced in the total (global) radiation on a horizontal surface due to the changes in the Sun Spot Number. The region considered is Chennai, the Capital city of Tamil Nadu. We have done the data analysis during the 23rd solar cycle, which began in May, 1996 and ended in December, 2008. This solar cycle lasted for about 12.6 year. The monthly average daily global radiation on a horizontal surface at Chennai has been calculated for this period without and with the effect of the changes in the sunspot number. The estimated value including the effect of sunspot number agrees better with the measured value. The variation produced in the monthly mean daily global radiation on a horizontal surface amounts to about 0.02%.

Keywords: Sun spot, Solar declination, Sunrise hour angle.

1. Introduction:

The earth's climate is changing continuously. The changes include both spatial changes and the temporal changes. The sun is the fundamental source of all energy in the climate system. Hence it is reasonable to assume that the variations in the solar output might be one of the causes of the climate changes (Joanna, 2000). The changes in the solar output due to the earth's orbital parameters are responsible for the climate changes over millennial time scales (Hayes et al. 1976). The changes in the solar output over century time scale are partly responsible for the Little Ice Age (Lean et al., 1992). The changes in the solar output during the 11-year solar cycle also affect the climate system. But, the change in solar irradiance from solar minimum to solar maximum is only about 0.1% which would cause a global mean increase in surface temperature of around 0.1K (Joanna, 1999).

The intensity of solar radiation keeps on attenuating as it propagates away from the Sun's surface. The solar radiation incident on the outer layer of the earth's atmosphere is termed as Extra Terrestrial Radiation (ETR). The solar constant is defined as the energy received from the Sun per unit time, on a unit area of surface perpendicular to the direction of propagation of solar radiation at the top of the earth's atmosphere when the earth is at its mean distance from the Sun. Measurements show that the value of solar constant fluctuates a little. But, an average value of $1367 W/m^2$ has been recommended by World Radiation Center, which has been used almost for all practical purposes (Frolich and Brusca, 1981) When the solar radiation reaches the surface of the earth, it is in the depleted form as it is subjected to absorption and scattering by various constituents of the earth's atmosphere. The solar radiation reaching the surface of the earth is influenced by the variations produced at the Sun itself, and the atmospheric conditions such as cloud cover, aerosol content, amount of trace gases present in the atmosphere, etc. The solar radiation received at the earth's surface in line with the sun is called Direct radiation. The radiation received at the earth's surface after being subjected to scattering in the atmosphere is called diffuse radiation. The sum of these two is termed as the total or Global radiation.

In this paper, the monthly average daily global radiation on a horizontal surface at Chennai has been calculated during the 23rd solar cycle which began in May, 1996 and ended in December, 2008. This solar cycle lasted for about 12.6 year. Chennai city is located at a latitude of 13^o N.

2. Variations in Extra Terrestrial Radiation:

The amount of Extra Terrestrial Radiation (ETR) received from the Sun per unit time, on a unit area of surface perpendicular to the direction of propagation of solar radiation deviates from the solar constant due to the following two reasons. First is that, the Earth revolves around the Sun in an elliptical orbit having a very small eccentricity with the sun at one of the foci. Consequently, the distance between the Earth and the Sun varies a little from day to day in a year. The second reason is that the radiation emitted by the Sun itself varies due to the changes in the sunspot number. The variable value of ETR received on a unit area in unit time due to the changes in the Sunspot number is given by the following equation (William, 1992).

I_{ext} = 1366.82 + (0.00771*R) ----------------------------(1)

where I_{ext} is the variable ETR due to the changes in the sunspot number, R is the Sunspot Number.

3. Daily Global radiation:

The Global radiation at any place is the sum of the direct radiation and diffuse radiation. Many researchers proposed different models to estimate the global radiation using the meteorological parameters such as cloudiness, air temperature, etc. But, the model given by Angstrom relating the global radiation linearly with the sunshine hours gives the best results worldwide (Hinrichsen, 1994). The global radiation at any given location as given by Angstrom model (Angstrom, 1924) and later modified by Prescott (Prescott, 1940) is as follows.

$H/H_O = a + b(S/S_O$---(2)

where H is the monthly average daily global radiation on a horizontal surface at a location, H_O is the monthly average daily extra terrestrial radiation on a horizontal surface at the same location, S is the monthly average of the sunshine hours per day at the given location, S_o is the monthly average of the maximum possible sunshine hours per day at the same location i.e., the day length on a horizontal surface, a and b are the regression coefficients obtained by fitting the observed data. H_O can be computed from the following equation (Firoz and Intikhab, 2004).

$H_D = (24/\pi)(Q_O x3.6)$ [1.0 +0.033 cos (360n/365)][ω sinϕ sinδ + cosϕ cosδ sinω] ----------------------------(3)

where H_D is the daily extraterrestrial radiation on a horizontal surface on the n^{th} day, Q_O is the solar constant, n is the day of the year (n=1 for 1^{st} January), ω is the hour angle at sunrise on the n^{th} day, ϕ is the latitude of the location and δ is the solar declination on the n^{th} day. This equation includes the solar variability due to the changes in the sun-earth distance. Now to incorporate the effect of sunspot number variation, we have to replace Q_O by equation (1). Hence, we get

H_D^1 = (24/π)(3.6) [1366.82 + (0.00771*R)] [1.0 +0.033 cos (360n/365)] [ω sinϕ sinδ + cosϕ cosδ sinω] ---(4)

where H_D^1 is the daily variable extraterrestrial radiation on the n^{th} day. The values of sunrise hour angle, the solar declination and the maximum possible sunshine hours on a particular day can be computed from the following equations (Cooper, 1969).

δ = 23.45 sin [360(284+n)/365] -----------------------(5)

$\omega = \cos^{-1}[-\tan\phi \tan\delta]$ ----------------------------------(6)

$S_O=(2/15)\,\omega$ ---(7)

The values of the regression constants a and b have been taken to be a=0.34 and b=0.32 (Veeran and Kumar, 1993) Hence, from equation (2), we have the following empirical equations to compute the monthly mean daily global radiation on a horizontal surface.

$H = H_O [a + b(S/S_O)]$-- (8)

$H^1 = H_O^1 [a + b(S/S_O)]$--------------------------------------(9)

where H is the monthly mean daily global radiation on a horizontal surface without including the effect of sunspot number, H_O is the monthly average daily extra terrestrial radiation on a horizontal surface without including the effect of sunspot number, H^1 is the monthly mean daily global radiation on a horizontal surface including the effect of sunspot number and H_O^1 is the monthly average daily extra terrestrial radiation on a horizontal surface including the effect of sunspot number.

3. Data and Analysis:

The monthly average sunspot number values are taken for the 23^{rd} solar cycle i.e., a period of about 12.6 years from May,1996 to December, 2008 (http://solar science.msfc.nasa.gov). The monthly average daily global radiation on a horizontal surface and the monthly average daily sunshine hours data for Chennai have been obtained from National Data Centre, India Meteorological Department, Pune, India. These data have been obtained for the above mentioned period. The global radiation has been measured using a pyranometer which can measure the incoming solar radiation in the wavelength range from 300-4000 nm. This pyranometer consists of a blackened Copper-Constantan thermopile covered by two concentric glass domes. The thermopile is calibrated such that the generated electromotiveforce (emf) is about 5microVolt/Watt/Sq.metre A typical pyranometer is shown in Figure 1. (http://www.imdpune.gov.in).

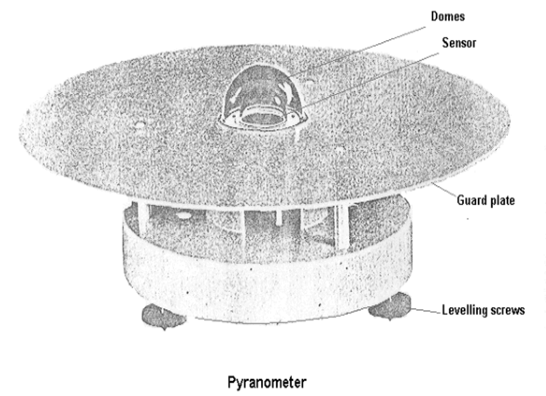

Figure 1: Installation view of a pyranometer

A few data gaps (7 data) were filled with the respective mean values. The value of Chennai's latitude has been taken as 13^oN i.e. $\phi=13^o$. After computing the values of solar declination and hour angle from the equations (5), (6) and (7), the monthly average daily extra terrestrial radiation on a horizontal surface have been calculated excluding and including effect due to the sunspot number using the equations (3) and (4). Then the monthly average daily global radiation on a horizontal surface has been calculated excluding and including effect due to the sunspot number using the equations (8) and (9). These two proposed empirical models have been tested with the observed values using the following the statistical error tests (Soler, 1990):

(i) Mean Bias Error (MBE)

$$MBE = (1/K) \sum (H^i_{cal} - H^i_{obs}) \text{ -----------------------------(10)}$$

where K is the total number of observations, H^i_{obs} is the i^{th} observed value of H and H^i_{cal} is the i^{th} calculated value of H.

(ii) Root Mean Square Error (RMSE)

$$RMSE = [(1/k) \sum (H^i_{cal} - H^i_{obs})^2]^{1/2} \text{ --------------------- (11)}$$

The test of MBE provides information on the long term performance of the models. The positive MBE values and negative MBE values give the average amount of over estimation and under estimation in the calculated values respectively. One drawback of this test is that over estimation in one observation will cancel the under estimation in another observation. The RMSE avoids this error cancellation problem. The test on RMSE provides information on the short term performance of the models. It allows a term by term comparison of the actual deviation between the calculated and the measured values. It is always positive. The demerit of this parameter is that a single value of high error leads to a high value of RMSE value.

4. Results and Discussion:

The monthly average daily global radiation on a horizontal surface at Chennai has been calculated excluding and including effect due to the sunspot number. These computed values have been compared with the observed monthly mean daily global radiation on a horizontal surface at Chennai for all the months of a year in Table-1. Results in Table-1 show that the computed values including the effect due to the sunspot number agree better with the observed values for all the months except October, November and December.

Table: 1 Estimated and observed values of monthly mean daily global radiation on a horizontal surface

Month	Observed value of H ($MJ/day/m^2$)	Computed Value of H ($MJ/day/m^2$)	Computed Value of H^1 ($MJ/day/m^2$)
January	17.20	16.9183	16.9206
February	20.85	19.5128	19.5153
March	22.65	20.7724	20.7759
April	23.07	21.7767	21.7804
May	21.56	21.0295	21.0331
June	20.08	19.0903	19.0941
July	19.18	18.2954	18.2989
August	18.74	18.0104	18.0138
September	19.33	18.5529	18.5561
October	15.94	16.4555	16.4581
November	14.20	15.2538	15.2566
December	14.34	15.2244	15.2268

Table 2: Performance evaluation test

Statistical Parameter	Model excluding the effect of Sunspot numbers	Model including the effect of Sunspot numbers
MBE	-0.5040	-0.5008
RMSE	1.3952	1.3942

Table 2 gives the results of the performance evaluation tests conducted on the two empirical models.

The variation produced in the monthly mean daily global radiation on a horizontal surface at Chennai amounts to about 0.017%. Though this variation seems so small that it cannot produce any considerable amount of change in the climate directly, it can affect the future climate through certain indirect feedback processes as discussed below.

1. The earth's stratosphere is heated up due to the absorption of UV rays under the enhanced solar radiation which leads to increased tropospheric Hadley circulation. This affects the distribution of atmospheric moisture (Manish and Rengaswamy, 2007).
2. The amount of galactic cosmic rays reaching the earth is reduced during solar maximum leading to less cloud formation. This in turn leads to global warming due to the increased incoming solar radiation. A 3% reduction in the cloud cover has been observed from1987 (solar minimum) to 1990 (solar maximum) which would result in global warming corresponding to 1-1.5 W/m^2 (Rossow and Cairns, 1995).

5. Conclusions:

- The variation produced in the monthly mean daily global radiation on a horizontal surface at Chennai varies between 0.012 and 0.082 during the 23rd solar cycle resulting in a mean variation of about 0.017%.
- The small variation produced in the solar insolation can affect the future climate through certain feedback mechanisms.
- The study of the future climate should be carried out paying attention to include the variations produced in the solar radiation due to the sunspot numbers.

Further studies can be done by monitoring the fluctuations in the galactic cosmic rays reaching the earth during a solar cycle.

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